National Aeronautics and Space Administration

Exploring the Dwarf Planets

The exploration of Pluto and other dwarf planets in our solar system is a complex undertaking. It may seem effortless when all you see is a finished product: a dramatic close-up image. But many scientific and technical considerations go into designing a successful space exploration mission.

This guide explains how science and technology come together to produce history-making missions to the edge of our solar system. It will show you how developing a scientific research project is like putting together a jigsaw puzzle. You will learn about the "Mission Lifecycle," which is the blueprint for spacecraft design, construction and launch. You will also learn about career opportunities in space exploration, from "rocket science" to mission management.

First, you'll learn about the science of exploring dwarf planets. You'll find out why NASA is conducting missions like New Horizons and Dawn. Think of this as the time when scientists have come together to define a particular research issue for which they need to build a spacecraft. This is much the same way that scientists build massive telescopes on high mountain tops in Chile and Hawaii to gather new data about the distant universe.

Next, you'll look into how NASA works with the scientists to create, launch and gather data from the spacecraft. This is a rigorous schedule of events that have to occur in a specific sequence in order to make sure the spacecraft performs exactly as it is designed to. Called the Mission Lifecycle, this plan has been honed over the decades through experiences in designing spacecraft of steadily increasing complexity.

Finally, you'll have a look at the types of professions needed to make a successful scientific mission happen. Spacecraft design, fabrication, launch and operation require literally thousands of people over the lifetime of the mission. Very few of these are scientists with PhDs, and in fact the spacecraft Team requires individuals with bachelors and masters degrees in diciplines as wide ranging as video communications and journalism, to electrical and mechanical technicians and machinists.

Acknowledgments

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Exploring Dwarf Planets

As the story goes, American astronomer Clyde Tombaugh discovered Pluto in 1930, using mathematical methods developed in the 19th century. The full story of how Pluto was discovered is actually more complicated, and more interesting.

In the mid-19th century, based on observations of the movements of Uranus, mathematician-astronomers Urbain Le Verrier of France and John Couch Adams of Great Britain independently began mathematical calculations to “predict” the existence of another planet beyond the orbit of the seventh planet. By their calculations, they discovered the planet Neptune.

In 1906, American astronomer Percival Lowell, working at his observatory in Flagstaff, Arizona, began a huge search for an even more distant planet, which he called Planet X. Lowell took thousands of pairs of photographs of specific areas of the sky to search for a distant moving object in the outer solar system, but by 1916 he abandoned his “needle in a celestial haystack” search. Meanwhile, American astronomer William H. Pickering had also been thinking that the motions of Uranus were a tad more complicated than could be explained by the gravitational influence of Neptune alone, and in 1919 he predicted the existence of a Planet X beyond the orbit of Neptune.

The search for Planet X did not resume until 1929, when American astronomer Vesto Melvin Slipher hired a 23-year-old assistant, Clyde Tombaugh, to resume photographing and comparing likely regions of the sky. The tedious work paid off on February 18, 1930, when Tombaugh observed Pluto’s star-like image shifting slightly between two images. Based on decades of work by many mathematicians and astronomers, Tombaugh had discovered Pluto.

The discovery of Pluto made headlines around the world! The name “Pluto” was suggested by an 11-year-old British student, Venetia Burney, and the international astronomy community accepted it because of her compelling argument that Pluto was the lord of the dark underworld. The naming of Pluto continued the tradition of naming planets after Greek mythological figures. The scientific rationale for identifying Pluto as a planet began to unravel soon after its discovery.

Astronomers figured out that Pluto was much too small to have any gravitational effect upon the orbits of Uranus or Neptune. In 1931, scientists estimated that Pluto had a mass close to that of Earth. By 1948, Pluto’s estimated mass had tumbled downwards to the mass of Mars, and then 1/500 of Earth’s mass by 1978. Detailed mathematical studies of the orbits of Uranus and Neptune showed that they were influenced by so-called “chaotic” behavior, not by some other distant planet's gravity. It began to look like the search for Pluto in the early 20th century had been a mathematical wild goose chase and the actual discovery of Pluto pure luck.

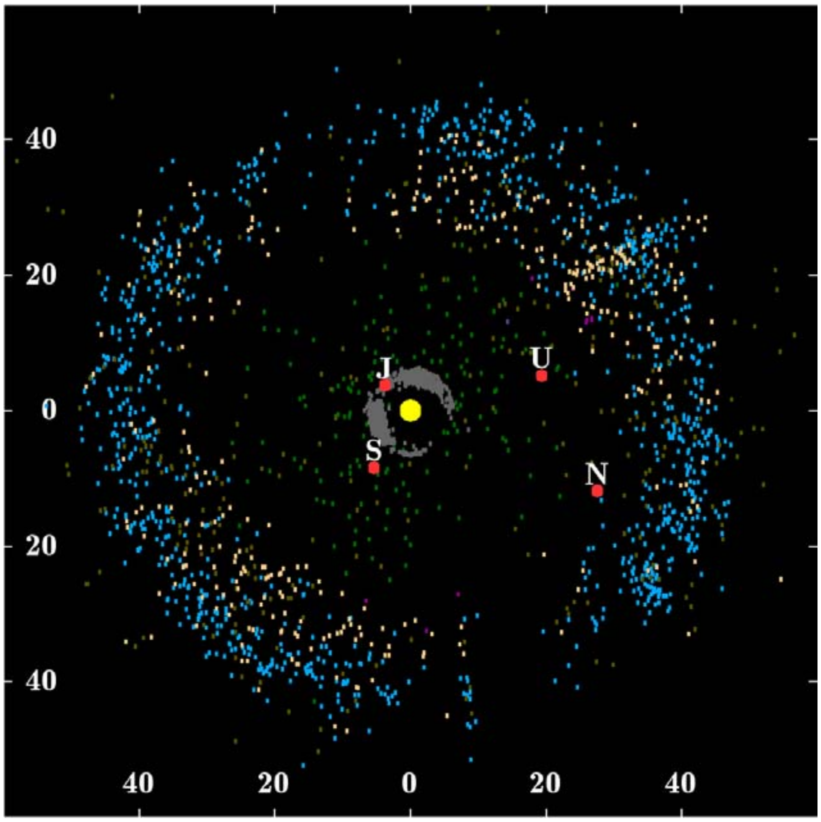
For decades following its discovery, astronomers and textbook writers alike called Pluto a planet. It was the largest object outside the orbit of Neptune discovered so far, and it satisfied two requirements for ranking as planet: it orbited the sun directly, and it was massive enough for gravity to shape it into a round object. But Ceres (discovered in 1801), Pallas (1802) and Juno (1804), and Vesta (1807) also meet these criteria. And they are not deemed planets. At the time they were discovered, between the orbits of Mars and Jupiter, scientists widely reported them as new planets in our solar system. Their days as planets ended once hundreds and then thousands of objects – now known as asteroids were also found in the same orbital region – now known as the Main Asteroid Belt. By around 1980, scientists understood that these four “planets” were asteroids.

Since 1992, astronomers have found many new objects orbiting beyond Neptune. Initially these objects were named Trans-Neptunian Objects (TNOs). Discovery of the first TNO, 1992 QB1, about 167 km in size, was followed by hundreds of others. In January 2005, astronomer Michael Brown, using a 200-inch telescope at the Mount Palomar Observatory, discovered a TNO that became known as Eris. It is nearly 27% more massive than Pluto. Eris was initially called the Tenth Planet. By the time of its discovery, astronomers had found hundreds of smaller TNOs. It was now time to reconsider what to call these objects. Although the International Astronomical Union had precise definitions and classification schemes for other astronomical objects, they did not have a definition for “planet.”

By the time Eris was discovered, mathematical models of how planets form from swirling disks of gas and dust were showing how specific kinds of objects could form in these disks. The parent star of a planetary system was located at the center of such a disk. In these models, local concentrations of matter that began as small “seed masses” grew rapidly until, like vacuum cleaners, they swept up remaining matter along their orbital paths. Once they grew to 500 km or so in size, these objects became round. What we call asteroids are the left-over rubble from the formation of planets. These models indicated that perhaps the best definition of a planet was an object that orbits its star directly, is a round body, and is the ONLY large object in its orbital neighborhood that is big enough to have absorbed all the other rubble in the area. Ceres and Pluto met the first two of these criteria but failed to satisfy the third. Thus astronomers decided to call them dwarf planets. Asteroids meet only the first of these criteria: they orbit the sun directly but are too small to be round. By August 24, 2006, the IAU came up with a system of defining solar system objects that was in line with observations and with models of how planetary systems form.

Many people did NOT like this change in Pluto’s status, at all. Even today, with 1,500 TNOs, including five dwarf planets (Pluto, Eris, Makemake, Haumera and Ceres), now known, many people wistfully hope for Pluto’s return to planetary status. A resolution introduced by members of the California State Assembly lightheartedly denounced the IAU for "scientific heresy," among other crimes. New Mexico's House of Representatives passed a resolution in honor of Tombaugh, a longtime resident of that state, declaring that Pluto will always be considered a planet while in New Mexican skies and that 13 March 2007 was Pluto Planet Day. In its 2006 words of the year competition, the *American Dialect Society* voted "pluto" its word of the year. To "pluto" is to "demote or devalue someone or something."

The IAU currently recognizes five dwarf planets: Ceres, Pluto, Haumea, Makemake, and Eris. Astronomers estimate that another hundred or so known objects in the solar system are dwarf planets. Up to 200 dwarf planets may be found when the entire region of the solar system known as the Kuiper Belt is explored, and that the number may exceed 10,000 when objects beyond the Kuiper Belt can be counted. Some astronomers have already identified several dwarf planets not yet designated by the IAU. In August 2011 Michael Brown published a list of 390 candidate dwarf planets, ranging from "nearly certain" to "possible." Brown currently identifies eleven known objects as "virtually certain" dwarf planets – the five accepted by the IAU plus 2007 OR10, Quaoar, Sedna, Orcus, 2002 MS4 and Salacia – and another dozen as "highly likely." The diagram below, courtesy of the Smithsonian Minor Planets Center, shows the positions of known Kuiper Belt objects – including many candidate dwarf planets!



Exploring Dwarf Planets with New Horizons and Dawn

NASA's ability to create complex spacecraft and send them into space, to arrive across the solar system within minutes of their planned time, does not come by accident or trial and error. At hundreds of millions of dollars per spacecraft, there can be no trial and error. Only meticulous planning will insure success. NASA calls this process the standard Mission Lifecycle Plan.

Imagine that you are taking a trip to visit your grandparents in another town hundreds of miles away. You know they want you to arrive by a specific time so that they can start dinner. First you have to decide how you are going to travel: By train? By plane? By car? Then you have to set aside enough money to cover the tickets, gasoline, tolls, hotels, food and any other travel expenses. You have to attend to other details like arranging for someone to take care of your pets and plants and pick up your newspapers and asking the post office to hold your mail. You have to pack your belongings, and on the day of the trip you have to take a shower, get dressed, have breakfast, and take care of a few other things. Such a long-distance trip involves many details that you have to allow for, so that you can arrive at your destination in time for dinner.

NASA created a detailed Mission Lifecycle Plan to make sure that New Horizons arrived at Pluto on July 14, 2015 at 6:49 am EST after having traveled billions of miles. Planning began when a team of scientists got together and came up with the idea of a mission to study Pluto. A Mission Lifecycle Plan consists of seven phases: pre-Phase Phase A, and Phases B, C, D, E and F. All kinds of people are involved at each phase, not just scientists and engineers.

Pre Phase-A. At NASA's request, the National Research Council develops 10-year plans for research in space science, soliciting input from hundreds of scientists across the country. The NRC prepares these so-called "decadal surveys" for *astronomy and astrophysics, planetary science, solar and space physics, biological and physical sciences in space, and Earth science and applications from space*. These reports identify research priorities for the next 10 years. NASA uses the NRC's recommendations in deciding what new missions to initiate. When NASA decides to pursue a "new start" for a space mission, it must include an estimated cost for the new mission in its budget plan, which is submitted to the President and to Congress. If the new mission is approved and funded, NASA requests proposals for building the spacecraft and developing the instruments it will fly. Scientists form teams to put together detailed plans for meeting the mission's science goals, building instruments, and launching the spacecraft. Typically 5 to 10 different teams will submit proposals to NASA in response to such an "Announcement of Opportunity" (AO). They only have about three to five months to create detailed plans, so they have to hurry! The most successful proposals are those that include scientists and engineers who have already had experience designing and building spacecraft and instrumentation. One member of a proposal team may be an expert on building imagers, having flown such devices on several spacecraft already. Generally members of proposal teams are world-renowned experts on specific topics related to the target of the mission, such as Mars, Pluto, or Ceres. They may partner with institutions that have built space-qualified hardware.

A mission proposal is a meticulous document that has to address every single issue raised by NASA in its AO. The proposal has to be in a specific format. NASA will reject a proposal that does not meet page count and format requirements, use the right print font, or meet other specifications. The stakes are so high in these competitions that proposal teams get help from specialists at their institutions who do nothing except check proposal drafts for “compliance.” They also format their proposals in an attractive way so that NASA reviewers will not literally fall asleep reading them. Graphic designers can provide colored figures and easy-to-read page layouts. The entire document is scoured for typographical, grammar and style, and punctuation errors.

The last 24 hours of proposal preparation are intense and terrifying. Teams wonder: did we cover all the required points? Did we submit the proposal on time? Did we receive a confirmation that it was received on time? A team leader, called the Principal Investigator (PI), will quickly get a message from NASA that the proposal was received and assigned a number and that it will soon be handed over to a review team. Proposal review teams consist of scientists not involved with NASA or any of its missions. They will evaluate proposals submitted in response to an AO and select the one that best addresses scientific objectives, is technologically doable, and comes within planned costs. After about six nerve-wracking months of review, PIs will be informed whether they won or lost. For winning proposals, discussions about final awarded costs and addressing reviewer comments will follow. Once a PI’s institution is awarded funding, the mission team begins what NASA calls Phase A development.

Phase A – Following a very big celebratory party, the PI convenes the first mission team meeting to go over what needs to be done and discuss whether reviewers caught any major technical or scientific problems in the proposal. During this year-long phase, plans set forth in the proposal are reworked to meet any new budget and payload limits imposed by NASA. A long list of specific requirements is developed for each instrument and spacecraft system so that engineers and technicians who will be building the equipment can insure that it will meet the needs of the mission. If it appears that one instrument may interfere with the operation of another, adjustments must be made. Although the mission proposal has addressed an enormous number of details, many more become apparent once Phase A work begins. Numerous planning meetings take place during Phase A. About twice a year the entire team gets together for three or four days to hear progress reports on instrument development and scientific goals. Spacecraft designers report on mathematical modeling of spacecraft mass and dynamics, and heat transport through instruments. Project managers discuss the mission timetable and critical dates for progress reviews. The first such review that NASA requires is the Preliminary Design Review (PDR). In the PDR, the mission team must demonstrate that its preliminary design meets all system requirements with acceptable risk within cost and schedule constraints and establishes the basis for proceeding with detailed design (Phase B).

Phase B - The next task before the mission team, in Phase B, is to create detailed mechanical drawings for every component of the spacecraft. Every nut, bolt, connector, cable, and thousands of other parts have to be identified for purchase or manufacture. Costs have to be negotiated with many different vendors. The mass, volume and power needs of each experiment have to be nailed down exactly. Detailed flight plans have to be mathematically modeled for many different potential launch dates and configurations. This work requires accountants, mission planners, contract specialists, administrative assistants, travel experts, freight handlers, electronics technicians, mechanical engineers, electrical engineers, thermal engineers and metallurgists, as well as information technologists and computer programmers. The most important meeting in Phase B is the Critical Design Review (CDR), in which the team must demonstrate that its design is detailed enough to support full-scale fabrication, assembly, integration, and testing.

Phase C – During this phase, a fully functioning version of each instrument is built and tested to make sure that designs were sound. At the same time, flight-ready equipment is built. Unlike test versions, flight equipment is often built under clean room conditions to avoid contamination. Technicians work in head-to-toe protective clothing.

This image shows the New Horizons spacecraft in a clean room.

Phase D – In this phase, flight-ready equipment built at different locations is shipped to a single location where it is assembled or “integrated” into the actual spacecraft. This is a nerve-wracking process because, if someone has made so much as a millimeter error in producing a part, the pieces may not fit together properly. The spacecraft, like many of its instruments, has been kept in a clean room, where the air contains fewer than 30 particles larger than 0.5 micrometers per cubic meter. Dust particles can contaminate experiments or cause electrical shorts. Workers in clean rooms wear “bunny suits” that cover them from head to toe and facemasks to avoid skin flakes and hair contamination. Once all the instruments are assembled in the spacecraft, they have to be tested under space flight conditions. The assembled spacecraft is placed in a vacuum chamber to simulate interplanetary space, bombarded by radiation, and subjected to intense shaking. Any loose cables will cause electrical problems, and the shaking that simulates the launch process will determine if there are any damaging “resonances” in the many instruments interacting with each other.

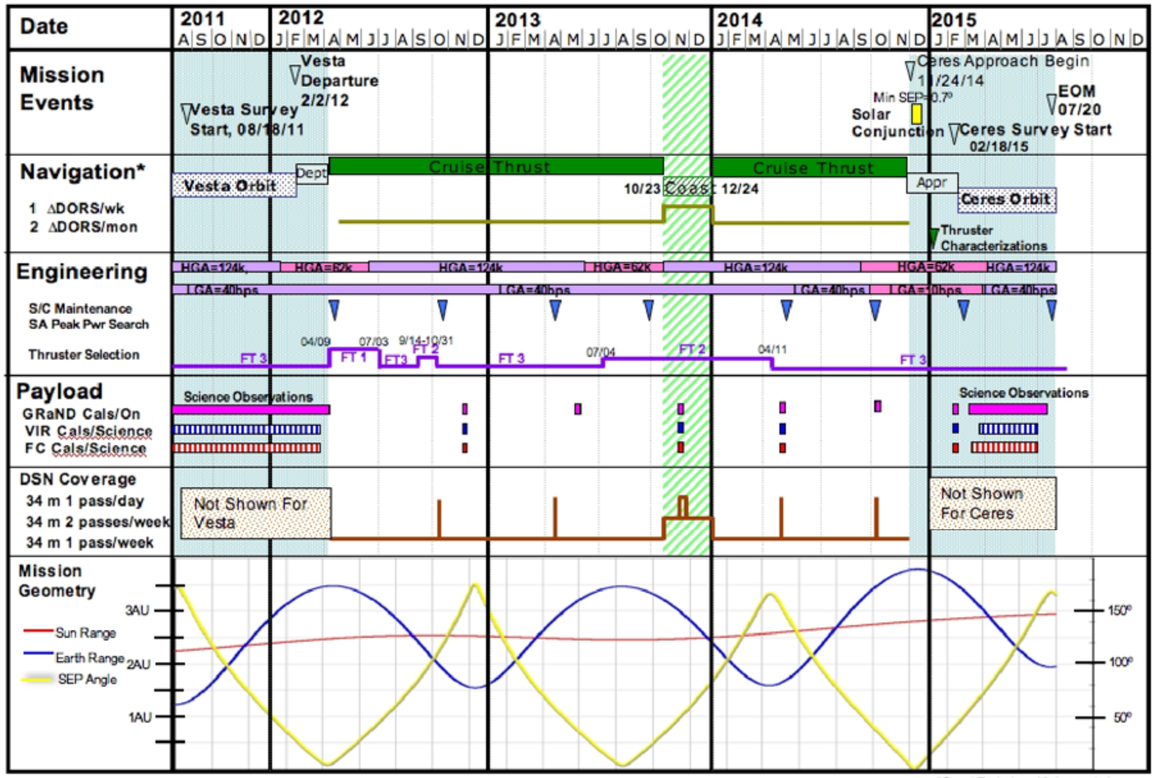
The spacecraft is then sealed in a dust-tight enclosure, often with a nitrogen atmosphere to prevent stray dust buildup, and transported to its launch site: Kennedy Space Center in Florida

or Vandenberg Air Force Base in California. There it is mated with its launch vehicle, and flight instruments are subjected to more tests. On the day of the launch, there is a very long check list of things to go through including making sure that the proper cables are connected, or disconnected, and that something as simple as dust covers have been removed. The end of Phase D occurs 30 minutes after launch.

In this image we see the Mars MAVEN spacecraft inside its sealed nosecone shroud being mated to an Atlas V rocket at Cape Canaveral.

Phase E – The science mission begins 30 minutes after launch when the spacecraft has been placed in its final trajectory, but there may also be many small trajectory changes to come. During this phase, the scientific instruments used during the flight are unstowed, activated, checked, and may begin to take specific kinds of measurements as the spacecraft travels to its destination. The spacecraft navigation system, which is not a science instrument, determines the current direction and speed of the spacecraft, and radios this information back to Earth so that mission planners can make any needed adjustments. Solar panels or other power generators are carefully monitored. Other “housekeeping” functions report about temperature, power and other mechanical changes in the spacecraft. Many of the spacecraft’s critical systems have separate backup systems in case of severe problems. Sometimes a cosmic ray particle may cause a computer glitch and the flight computer will have to be re-booted, or new updated software will have to be installed.

For long trips, the spacecraft may be placed in a hibernation mode. Enough power is used to run the heaters to keep the spacecraft instruments warm, but very little data is returned. Hibernation can go on for months or years depending on whether the spacecraft’s destination is Mars or the outer planets. Throughout the hibernation period, spacecraft engineers on Earth receive and transmit messages to the spacecraft to make sure it is “alive” and there are no problems developing. Once the spacecraft gets close to its destination, usually within a few million kilometers, it starts to operate in its full data-collecting mode, sending data back to Earth at regularly scheduled times. These download times are arranged by NASA’s Deep Space Network. Other spacecraft beyond Earth orbit are also downloading their data to the network, so each mission has its own special time. Here, for example, is the science timeline for the Dawn mission, which visited asteroid Vesta and the dwarf planet Ceres.



*Coast Periods < 10 days not shown

The New Horizons spacecraft has seven science instruments, designed to measure radiation levels, radio energy, and dust grain impacts, and of course to take many pictures of Pluto and its environment. The entire spacecraft has a mass of 478 kg (1,054 lb.) and uses 228 watts of electrical power – about equal to the power consumed by four 60-watt bulbs in your home! The cost of the mission (including spacecraft and instrument development, launch vehicle, mission operations, data analysis, and education/public outreach) is approximately $650 million over 15 years (2001–2016). Details about the instruments can be found at http://pluto.jhuapl.edu/Mission/Spacecraft/Payload.php.

LORRI—Long Range Reconnaissance Imager – is a long-focal-length imager designed for high-resolution photography at visible wavelengths. The instrument is equipped with a high-resolution 1-megapixel charge-coupled-device (CCD) imager with a 208.3 mm (8.20 in.) aperture giving a resolution of 5 μrad (~1 asec). Its overall mass is 8.6 kg (19 lb), with the Optical tube assembly (OTA) weighing about 5.6 kg (12 lb). Principal investigator: Andy Cheng, Applied Physics Laboratory, Data: LORRI image search at jhuapl.edu

SWAP—Solar Wind At Pluto – measures particles with energies of up to 6,500 volts. Because the solar wind is so tenuous at Pluto's distance, this instrument has the largest aperture of any such instrument ever flown. Principal investigator: David McComas, Southwest Research Institute

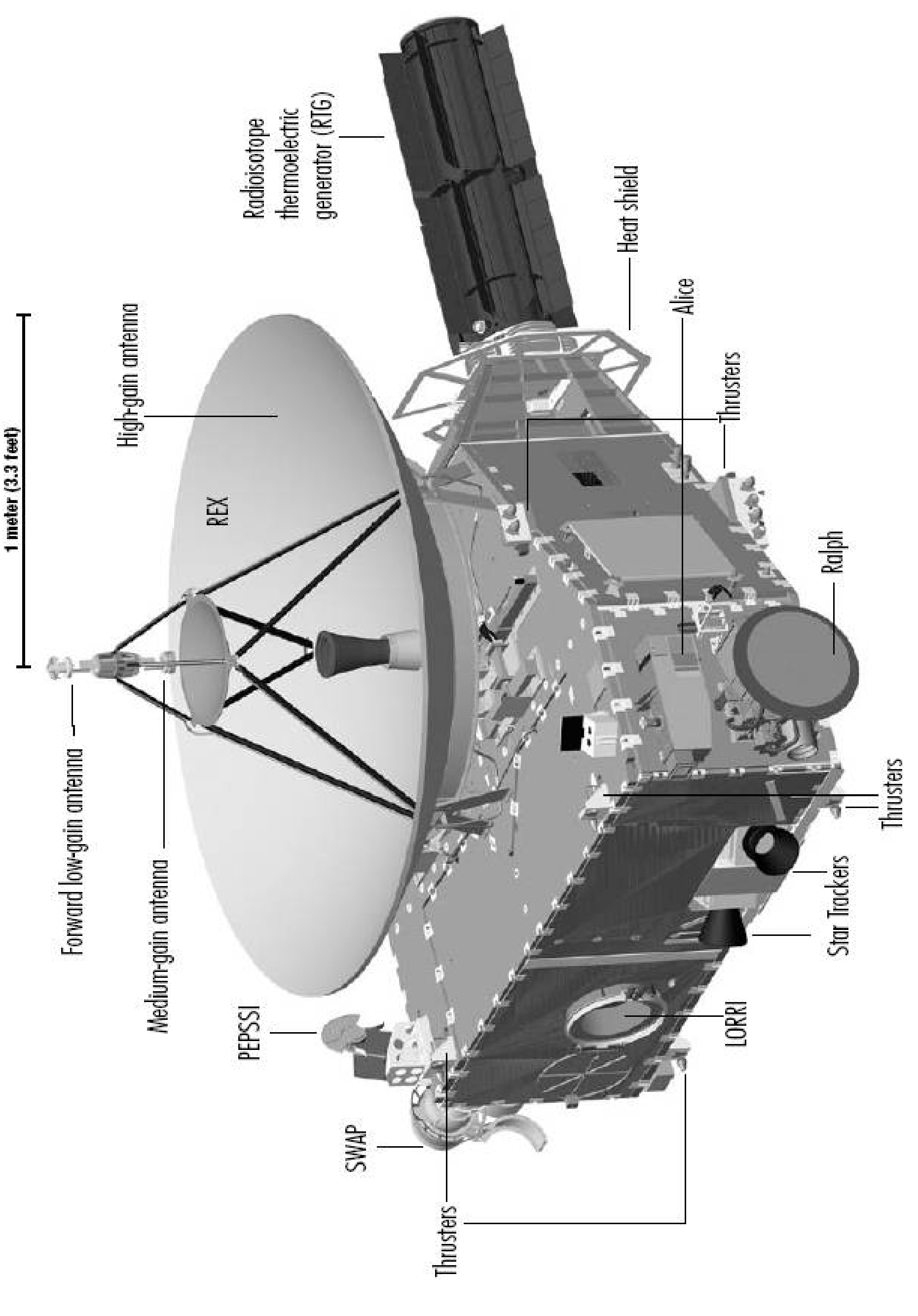
PEPSSI - Pluto Energetic Particle Spectrometer Science Investigation – is an ion and electron sensor that detects particles with energies up to 1 million volts. Principal investigator: Ralph McNutt Jr., Applied Physics Laboratory

Alice – an ultraviolet imaging spectrometer – resolves 1,024 wavelength bands in the far and extreme ultraviolet (from 50–180 nm), over 32 view fields. Its goal is to determine the atmospheric composition of Pluto. This Alice instrument is derived from another Alice that is aboard ESA's Rosetta spacecraft. Principal investigator: Alan Stern, Southwest Research Institute

Ralph—a telescope and color camera – has a 6 cm (2.4 in) aperture. Ralph has two separate channels: a visible-light CCD imager (MVIC - Multispectral Visible Imaging Camera) with broadband and color channels, and a near-infrared imaging spectrometer (LEISA – Linear Etalon Imaging Spectral Array). LEISA is derived from a similar instrument on the EO-1 mission. Ralph and Alice were named after characters on the 1950s television series "The Honeymooners." Principal investigator: Alan Stern, Southwest Research Institute

SDC—Student Dust Counter – was built by students at the University of Colorado, Boulder. It will operate continuously through the nine-year voyage to make dust measurements. It consists of a detector panel, about 460 mm × 300 mm (18 in × 12 in), and an electronics box within the spacecraft. The detector contains 14 polyvinylidene difluoride (PVDF) panels – 12 science and two reference – that generate voltage when impacted. Effective collecting area is 0.125 m^2 (1.35 sq ft). No dust counter has operated past the orbit of Uranus. A 13-minute film about the SDC garnered an Emmy award for student achievement in 2006. Principal investigator: Mihaly Horanyi, University of Colorado, Boulder

REX - Radio Science Experiment will use an ultrastable crystal oscillator (essentially a calibrated crystal in a miniature oven) and some additional electronics to conduct radio science investigations using the communications channels. These are small enough to fit on a single card. Since there are two redundant communications subsystems, there are two, identical REX circuit boards. Principal investigators: Len Tyler and Ivan Linscott, Stanford University.


1 meter (3.3 feet)
Forward low-gain antenna
Medium-gain antenna
High-gain antenna
REX
Radioisotope thermoelectric generator (RTG)
Heat shield
Alice
Thrusters
Ralph
Thrusters
Star Trackers
LORRI
PEPSSI
SWAP
Thrusters

How STEM Careers Make the Mission!

What kinds of people does it take to design, build, launch, and analyze data from missions like New Horizons and Dawn? Exactly what kinds of careers go into the making of a successful robotic mission?

In the previous essay, we just looked at the Mission Lifecycle that begins with Phase A and ends with Phase F. Each of these phases involves its own special mix of talented people who work for NASA directly as civil servants, or for companies or organizations that are contractors to NASA. Contractors can be employed by companies as large as Boeing and Lockheed Martin, or a small company with only a handful of employees that does specialty work.

Scientists - For missions like New Horizons and Dawn, work begins with scientists: experts with Ph.Ds in fields such as planetary science, meteorology, geophysics, geology, astronomy, physics, chemistry, and biology. A mission is designed to answer a particular set of compelling questions identified by scientists to advance understanding of some distant object, process or condition. Scientists working on missions must be familiar with the cutting-edge technology that will enable them to study distant solar system objects. They also must know to analyze and interpret data and test, or develop new, hypotheses or theories of how things work. They need to know why a particular measurement needs to be made, what kind of instrument is needed to make the measurement, and how the instrument is likely to be designed and operated. They must be proficient in physics, chemistry or another specialty subject and be highly skilled in advanced mathematics. Some scientists focus on experimental studies, while others focus on observational or theoretical work. The most important activity of a scientist is to advance knowledge, publish and present new results so that other scientists may build upon their efforts. Although science is often an individual activity, groups of scientists can collaborate to bring additional resources to bear upon specific problems. Although the idea for a specific spacecraft mission may have been developed by a single individual, it will be the efforts of many teams of scientists that will bring the idea to fruition. This process can often begin with a one-page concept developed by a Principal Investigator, and it can evolve quickly into a 100-page proposal to NASA involving dozens of scientists and engineers who request funding for Pre-Phase A work.

Engineers - Scientists usually work closely with a variety of engineers to design new instruments for research. This is true in a laboratory where an idea for a new instrument can be tested by building a prototype. During this prototyping period, many different approaches to making a particular measurement, building a robotic system, or creating new imagers and other devices are tested, improved, or sometimes discarded.

Electrical engineers design electronic circuitry at the laboratory bench, using complex calculations, computer modeling, and a detailed practical knowledge of what components are available “off the shelf.” They often assemble actual circuits at the bench, using soldering irons and circuit boards.

Mechanical engineers are involved in the mechanical design of an instrument. Mechanical engineers understand physics, as well as the properties of materials, fabrication techniques, and cost-benefit trading. Given limits on the mass and size of an instrument imposed by spacecraft design, they figure out how to fit everything together so that the instrument will work and is robust enough to survive overland transport, interfacing with other equipment, and the physical forces of a rocket launch.

Systems Engineers design the overall operation of a spacecraft or launch vehicle and make sure that all parts work together. They ensure that subsystems will work properly, and at exactly the right time, to carry out movements, power transfers, startup of instruments, ignition of thrusters and many other operations. All subsystems must be designed, tested, and monitored during flight according to a detailed timeline.

Attitude Control Engineers make sure that the spacecraft is pointed in the right direction during flight and science operations. They work with spacecraft gyros and thrusters to change direction and trajectory as needed.

Optical Engineers design systems to detect and focus light, magnify images, and relay images to data storage and to Earth. Spacecraft imagery is made possible by engineers who design a telescope or camera to operate within the cramped confines of a spacecraft to provide the best possible pictures. Familiar systems like reflecting telescopes (mirrors) or refracting telescopes (lenses) are the core of spacecraft camera designs, modified to be folded into amazingly small volumes.

Flight Engineers sit at computer consoles and monitor spacecraft functions during flight and science operations. They identify problems as they arise by comparing expected ranges of spacecraft system performance with what a system is doing at the moment. They upload commands to the spacecraft and also make other real-time updates and adjustments to the spacecraft as requested by other engineers and scientists on the mission team.

Computer Scientists are involved in designing the computer system used on a spacecraft to gather, format, store and transmit data collected by instruments. They design detailed timing schedules for data packets to flow around the spacecraft and make sure that a spacecraft's system architecture provides adequate safeguards against loss of data from radiation damage. They select or design a spacecraft's flight computer system and all of its electrical interfaces to science instruments and other flight subsystems. They determine whether off-the-shelf systems are available, or if previously-flown flight computer systems are adequate to meet mission requirements.

Software Engineers work closely with Computer Scientists, Engineers, and Scientists, writing critical software used on the spacecraft and on the ground. They have mastered many specialty computer languages and are intimately familiar with data formats and computer logic. During a mission, they may have to quickly modify and recompile software on a spacecraft to improve its efficiency or to correct problems.

Propulsion Engineers are literally “rocket scientists” who design spacecraft thrusters for navigation and trajectory change. They monitor all aspects of fuel use and the “delta-V” (change in velocity) available to a spacecraft from its fuel reserves.

Technicians fabricate spacecraft electrical and mechanical systems under the direction of engineers and scientists. They work at the lab bench, in clean rooms, and at parts fabrication centers. They use everything from soldering irons to metal lathes and large machinery to assemble spacecraft.

Management – Program Managers are in charge of keeping track of the progress of many NASA spacecraft within a particular theme area such as Mars exploration or exoplanet exploration. They keep track of program budgets and scientific returns on funded research, and they consult with the scientific community to make sure that the missions they are funding are relevant to the current direction of scientific inquiry. Project Managers are responsible for individual missions such as New Horizons or the Hubble Space Telescope. They work closely with mission PIs and engineers to track mission progress and report on missions to Program Managers. If a PI encounters any problems with funding, contracts, or larger NASA policy issues, the Project Manager can be invaluable in resolving these problems.

Procurement – Someone has to purchase the off-the-shelf parts that go into the creation of a spacecraft. Procurement officers create purchase orders for mission scientists and engineers that are sent to many different companies and institutions to order parts and services. They double-check that adequate funds are in the mission account to purchase goods and services. They coordinate the delivery of purchased goods to the scientist or engineer who requested them.

Contracting – Contracts experts have a deep understanding of how to write agreements for obtaining services from individuals and organizations. NASA contracts must comply with federal acquisition regulations. Vague language can lead to confusion about who is responsible for what action, how the effort will be monitored for quality and safety, and over what time period the service will be requested.

Accounting – NASA will not give a Principal Investigator’s institution all of the requested money at once. Instead, funding will be spread out over the planned life of the mission from Phase A to Phase F. Most of the funding for a mission will often be used to purchase a launch vehicle and build science instruments and spacecraft subsystems. There can be dozens of institutions and groups involved in this funded effort. Each will have agreed upon a schedule of funding for its particular service. Each will have its own accounting specialist who oversees how the money is being paid out and what bills need to be paid and monitors cash flow throughout the mission. Overall, the PI’s institution will be in charge of paying out money to partner institutions and will have to keep very close tabs on whether the mission is over or under budget.

Travel – Scientists and engineers will attend many meetings during the mission life cycle. Most may be teleconferences of Web-based meetings, but as instruments are being built and integrated, there will be many trips to inspect progress and perform troubleshooting. Travel arrangements are generally made by the institutional travel office or an outside travel agency. Individuals have to get permission to travel and explain the reasons for the trip. Travel costs must stay within budget.

Graphics – The need for visual imagery, web page design, proposal layout, and promotional products to present a mission to the public and its NASA sponsors usually requires sophisticated graphic design. The visual appearance of a multi-million-dollar proposal can be a key element in whether that proposal is funded, if its design makes it easy to quickly understand.

Education – NASA is very concerned that scientific and engineering breakthroughs become integrated into the STEM content that students are being asked to master in the 21st century classroom. Many missions set aside funds from their NASA award to support teacher interns or other education specialists who will be asked to translate science and engineering content into classroom resources and teacher training.

Communication – If a tree falls in the forest and no one is there, did the tree actually fall? This old puzzle comes to life as a mission is being developed and later as it starts to return its scientific data. Federal tax dollars pay for NASA missions, and taxpayers are a major audience for communicating scientific discoveries. Communications about space missions include press releases, videography, and social media. NASA and many of the institutions it works with have dedicated professionals who do this work. New discoveries may be announced at science conferences in science journals, or at NASA press briefings.

Website Development – Soon after a mission is selected and named, a website is created to provide basic information about it. NASA and Principal Investigators' institutions maintain mission websites, designed by Webmasters and graphic designers. Content may be written by mission scientists. Social media channels may be created for a mission on Twitter, Facebook, and blog sites.

Information Technology –Since the dawn of space research in the late 1950s, all NASA missions have employed some kind of computer system to calculate trajectories, archive data, and make data accessible to scientists and others. Today these efforts are so complex that they require computer and information technology specialists to monitor computer usage and to build in safeguards so that systems cannot be hacked.

To read more about these careers, have a look at the many interviews located at a variety of NASA websites!

Solar System Exploration Biographies http://tinyurl.com/pca2w76

NASA Occupations http://nasajobs.nasa.gov/jobs/occupations.htm

Women@NASA http://women.nasa.gov/

NASA Women of STEM http://www.nasa.gov/education/womenstem/

NASA Scientists http://imagine.gsfc.nasa.gov/features/bios/

Here we see high school students from Hampton, Newport News, Williamsburg and James City and York County who visited the NASA Langley Research Center in Hampton, Virginia to learn more about careers in engineering. Credit: NASA/Sean Smith.

Exploring the Dwarf Planets

Images courtesy of NASA, ESA, JPL, and A. Feild (STScI)

Exploring the Dwarf Planets

In 1930, Clyde Tombaugh discovered an object in the outer solar system that he identified as a planet. The object was named Pluto. Pluto's moon Charon was discovered in 1978, and four more moons – Nix, Hydra, Kerboros, and Styx – were discovered between 2005 and 2012.

Since 1992, scientists have discovered over 1000 new outer solar system objects – all small bodies -- that orbit the Sun beyond Neptune. And mathematical studies of how planets form from swirling disks of gas and dust have shown that to become a planet, an object has to have enough mass to clear the rubble in its neighborhood.

In 2006, the International Astronomical Union (IAU), which is in charge of assigning designations to celestial bodies, decided that recent discoveries warranted a new definition of "planet." The IAU defined three categories of solar system objects. A "planet" is a celestial body in orbit around a star, with sufficient mass to render it round and to clear its orbital neighborhood of rubble. A "dwarf planet" is a body that is too small to clear its orbital neighborhood. All other bodies (except satellites of other bodies) are now defined as "small solar system bodies" (this category includes asteroids). By adopting this new classification system, the IAU "demoted" Pluto to dwarf planet status – leading to a lot of passionate discussion among scientists, citizens, and late-night talk show hosts!

Scientists can learn a lot about the inside of a dwarf planet by making very precise measurements of its diameter and mass. From these measurements, average densities (mass divided by volume) can be figured out. The density of an object gives us a clue as to whether it is mostly rocky or mostly icy. By combining various mixtures of materials with known densities in the laboratory, we can make a very good guess about a dwarf planet's internal composition.

The table below gives the sizes of the five identified dwarf planets as a percentage of Earth's moon's value in diameter and mass.

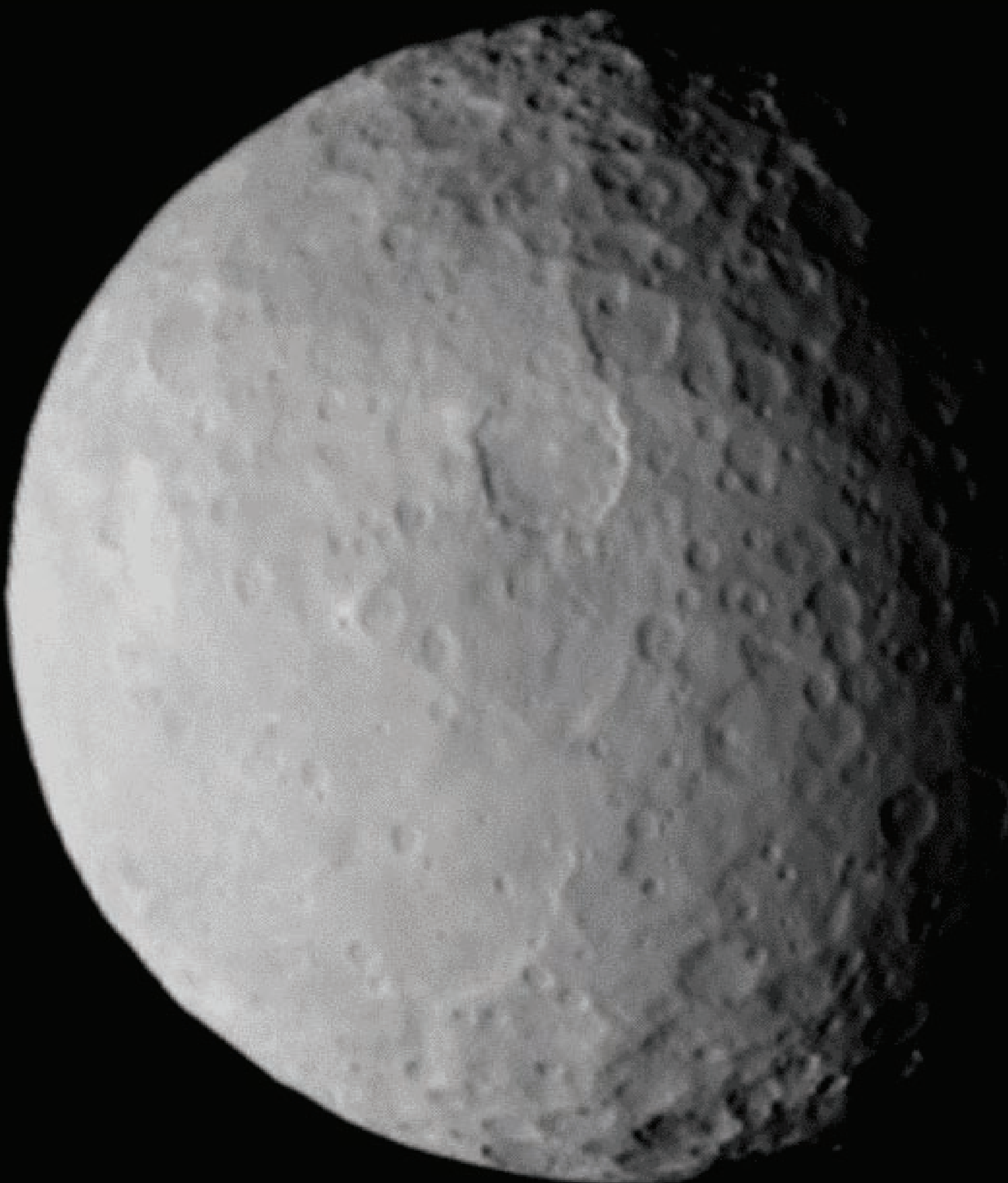
Dwarf Planet	Diameter (Moon)	Mass (Moon)	Density (kg/m^3)	Orbit Period (yrs)
Ceres	**27%**	**1.3%**	**2,200**	**4.6**
Pluto	**66%**	**17.8%**	**2,100**	**248**
Haumea	**36%**	**5.5%**	**3,000**	**283**
Makemake	**46%**	**5.4%**	**1,800**	**310**
Eris	**67%**	**22.7%**	**2,500**	**557**

Space Math Challenge!

Typical surface rock on Earth (granite) has a density of about 3,000 kg/m^3, while solid water ice has a density of about 900 kg/m^3. What do you think the dwarf planets are mostly made from? **Now try this:** Suppose two thirds of the volume of a dwarf planet is granite and one third is ice. What is the average density of the dwarf planet?

Answers: Haumea= mostly rock; Makemake= mostly ice; Ceres, Pluto, Eris about 50/50 rock and ice.
Now try this: Density = (2/3)x3000 kg/m^3 + (1/3)x900 kg/m^3 = 2,300 kg/m^3

Exploring Dwarf Planet Ceres



Images of Ceres during rotation. (Image credit: NASA/JPL/Dawn)

Exploring Dwarf Planet Ceres

One of the most exciting events that astronomers can experience is to see a celestial object clearly for the first time. That's what recently happened with the dwarf planet Ceres. This image of Ceres was taken by NASA's Dawn spacecraft on May 23, 2015, from a distance of 3,200 miles (5,100 kilometers). Astronomers were amazed to see that its surface is heavily cratered and shows spots of mysterious white material in several locations.

Ceres' surface – untouched by erosion or internal melting and volcanism, as Earth's surface has been – is believed to be 4.6 billion years old, as old as our solar system. Most of the impacts that produced the craters on Ceres probably occurred during a period in solar system evolution that scientists call the Late Heavy Bombardment Era, which ended about 3.8 billion years ago. Heavily cratered surfaces like that of Ceres are seen all across the solar system, most notably on our own moon, Mercury and even the recently mapped asteroid Vesta.

Counting and measuring craters on Ceres can provide insights into the cratering process that created its surface. It appears to have fewer large craters than scientists had expected to see, a possible indication that most of the material that came together to form Ceres was smaller asteroids.

The new images also tell us that the surface of Ceres has more than just craters and mountains. Brilliant white spots can be found near the bottoms of several craters. Such features have never before been seen on an asteroid or a dwarf planet.

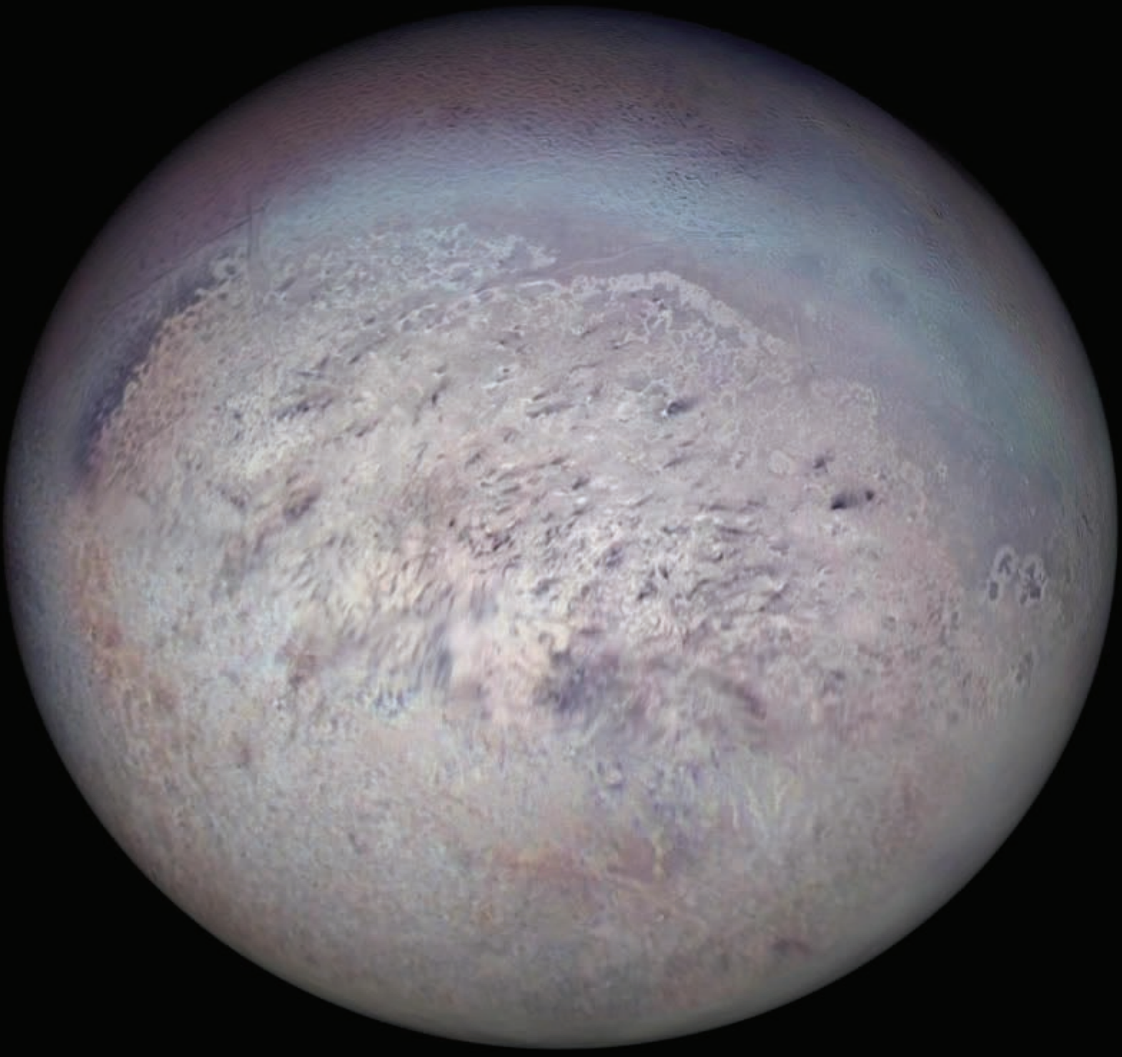
What is it? How can we find out? The scientific exploration of this world continues!

Space Math Challenge!

The surface of Ceres is covered by approximately 10,000 craters larger than 10 km across. If they formed during the 600-million-year-long Heavy Bombardment Era, about how long would you wait between the impacts? **Now try this:** With the help of a millimeter ruler, a printed copy of the image, and knowing that the diameter of Ceres is 938 km, what is the diameter, in kilometers, of the largest crater you can see in this image?

Answer: Time = 600 million years/10,000 impacts = 60,000 years!
Now try this: Solve the proportion for X, the diameter of the crater: (938 km/184mm) = (X/23mm) = 120 km

Triton: The Twin of Pluto ?



Voyager 2 image of Triton showing smooth, craterless surface. (Image credit:NASA/JPL/Voyager)

Triton: The Twin of Pluto?

	Pluto	Triton
Diameter:	**2,368 km**	**2,700 km**
Mass:	**1.3×10^{22} kg**	**2.1×10^{22} kg**
Density:	**2,000 kg/m^3**	**2,100 kg/m^3**
Temperature:	**33 k - 55 k**	**38 k**

Close-up of Triton's surface (NASA/Voyager)

Solar system bodies, like Ceres or our moon, typically have craters as much as 10 km deep. Triton originally may have had such a lumpy surface 4 billion years ago. But now it looks smooth. It is possible that over millennia, Triton's surface was mostly covered by emissions from cryovolcanos. It is possible that Pluto's surface could be featureless, too, if its surface is as active as Triton's!

Over the decade that it took for NASA's New Horizons spacecraft to fly to Pluto, scientists have been hypothesizing about what they might discover there. We've already learned enough about Pluto to know that a near-twin-world exists in our solar system: Neptune's largest moon, Triton.

Triton is only slightly larger than Pluto. Both worlds have similar surface materials, such as nitrogen, methane and carbon monoxide. Their diameters, masses and densities are amazingly similar. Both Triton and Pluto may also have originated within the Kuiper Belt. The capturing of Triton by Neptune probably melted a large part of its surface.

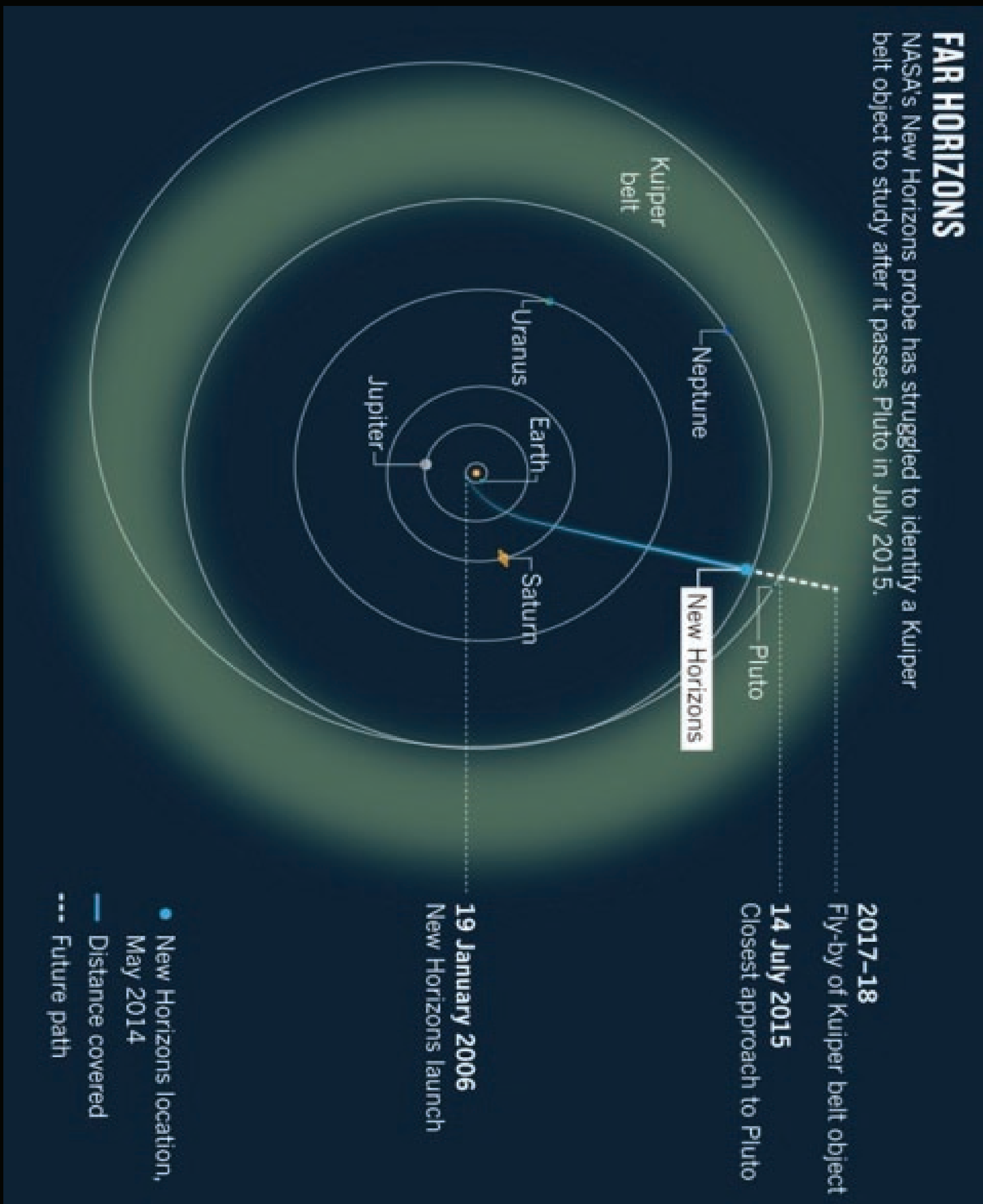
Voyager 2 images show that Triton is still geologically active, with geysers called cryovolcanos emitting water ice plumes. Being so close to the massive planet Neptune, gravitational forces acting on Triton may generate enough internal heat to cause geysers of liquid water along cracks in Triton's surface. Pluto is not thought to be as active as Triton, because it doesn't share the same capture history. However, Pluto's moon Charon tugs and pulls on the dwarf planet's surface, perhaps causing some form of cryovulcanism to resurface Pluto over billions of years.

Space Math Challenge!

What would be the average rate at which the Triton craters were filled-in over this period of time in units of millimeters per millennia? **Now try this:** Triton's surface area is 23 million km^2. If it was covered to a depth of 10 km, what percentage of Triton's total volume had to be recycled onto the surface by the cryovolcanoes?

Answer: 10 km deep/4 billion years = 10,000,000 millimeters/4,000,000 millennia = 2.5 mm/millennia.Now try this: $V = 4/3 \pi R^3$ so for R = 1,350 km, V = 10 billion km^3, so the percentage = 100% x (10 km x 23 million km^2)/10 billion km^3 = 2.2%

The Amazing Journey to Pluto



Credit: NASA/JHUAPL

The Amazing Journey to Pluto

Our solar system is so vast that it is almost impossible to think about its scale in terms of miles or kilometers. One way we can bring these enormous distances 'down to Earth' is to think in terms of travel times.

In a commercial jet liner, you could travel once around Earth in about 50 hours (not including stops for refueling!). It would take about 500 hours to get to the moon in the same plane. The much faster Apollo spacecraft made the trip in about 80 hours. The fastest spacecraft trip to Mars, made by Mariner 7 launched in 1969, took 128 days. The Soviet Venera 1 spacecraft made it to Venus in 97 days, and Mariner 10 took 147 days to get to Mercury. To get from Earth to the outer solar system takes years. To measure such vast distances, scientists use the Astronomical Unit or AU, which is the distance between Earth and the sun (150 million km or 93 million miles).

The slowest methods of interplanetary travel use gravity assists to save fuel and cost. The fastest methods use a very large launch vehicle to boost a spacecraft into an interplanetary trajectory at a high velocity. The spacecraft then coasts the rest of the way!

Starting from launch on January 19, 2006, and with a gravity assist from Jupiter along the way, NASA's New Horizons spacecraft took 9 years and 5 months to get to Pluto, 39 AU from the Sun. It traveled at an average speed of 4.1 AU/year.

Deep-space missions can take up to 10 years from development to launch. For New Horizons, it took close to 20 years from the time that scientists conceived of the mission to the time it reached its destination!

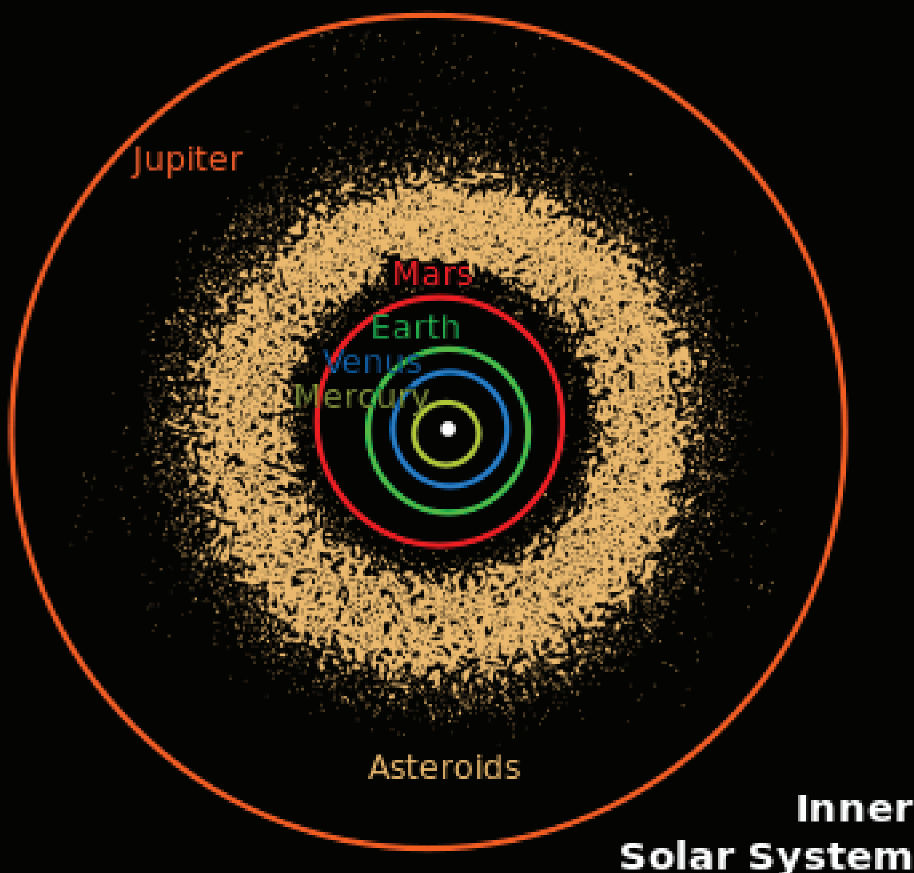
Spacecraft	Cost	Launched	Distance	Time	Speed
Pioneer 10	**$350 million**	**1972**	**30 AU**	**10 yr 10 mo**	**2.8 AU/yr**
Pioneer 11	**$350 million**	**1973**	**86 AU**	**39 yr 5 mo**	**2.2 AU/yr**
Voyager 1	**$450 million**	**1977**	**69 AU**	**20 yr 8 mo**	**3.3 AU/yr**
Voyager 2	**$450 million**	**1977**	**108 AU**	**37 yr 10 mo**	**2.9 AU/yr**
New Horizons	**$700 million**	**2006**	**39 AU**	**9 yr 5 mo**	**4.1 AU/yr**

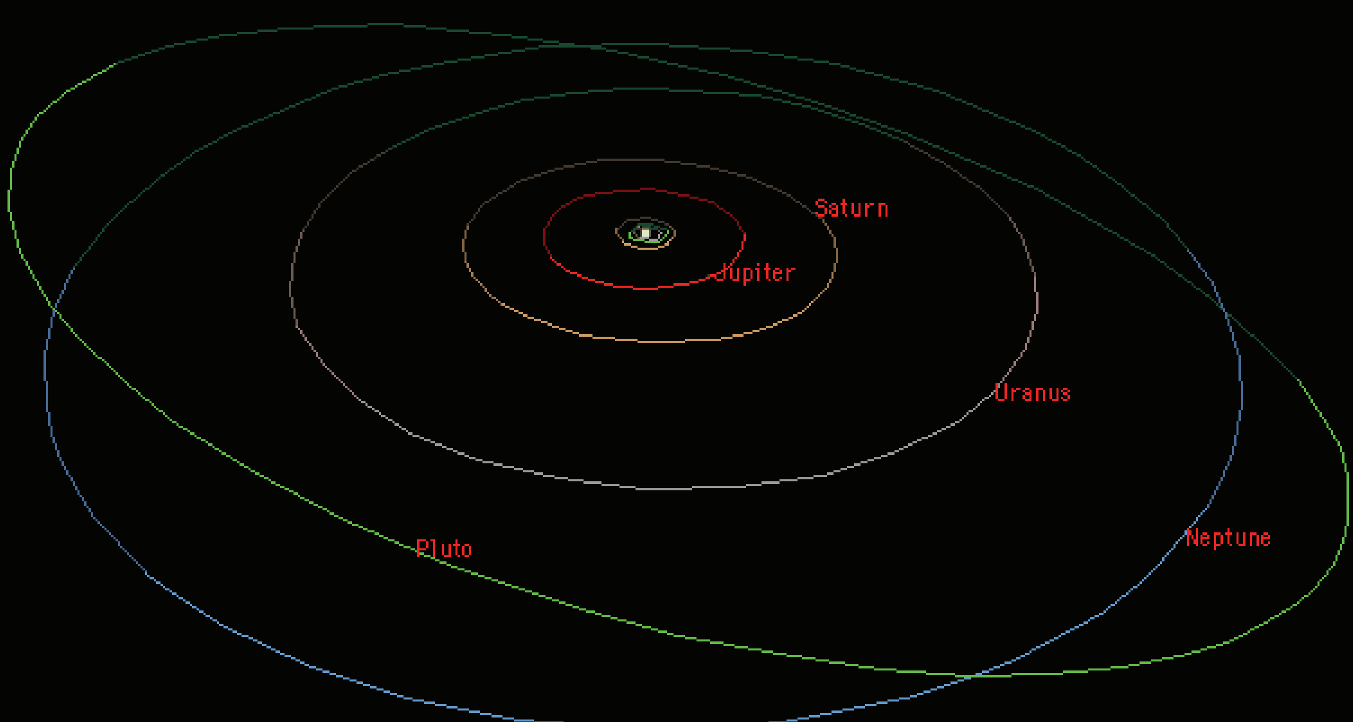
Space Math Challenge!

If 1 AU/year equals 4.8 km/sec (11,000 mph) how fast was the fastest spacecraft traveling in km/sec and mph? **Now try this:** Like light, radio signals in space travel at a speed of 300,000 km/sec. If it takes 8.5 minutes for a signal to travel 1 AU, what will be the round-trip time, in hours, for a radio signal to travel from Earth to each spacecraft and back to Earth at the distances shown in the table?

Answers: New Horizons was the fastest at a speed of 4.1 x 4.8 km/s = 20 km/sec or 45,000 mph.
Now try this: Pioneer 10: 30 AU x (8.5 min/AU) = 255 minutes one-way, and so 8.5 hours round-trip. Pioneer 11: 86 AU x (8.5 min/AU) x(1 hr/60 min) x 2= 24.4 hrs; Voyager 1: 69 AU x (8.5 min/AU) x (1hr/60 min) x 2 = 19.6 hrs; Voyager 2: 108 AU x (8.5 min/AU) x (1 hr/60 min) x 2 = 30.6 hrs; New Horizons: 39 AU x (8.5 min/AU) x (1 hr/60 min) x 2 = 11.1 hrs.

Exploring Interplanetary Communication





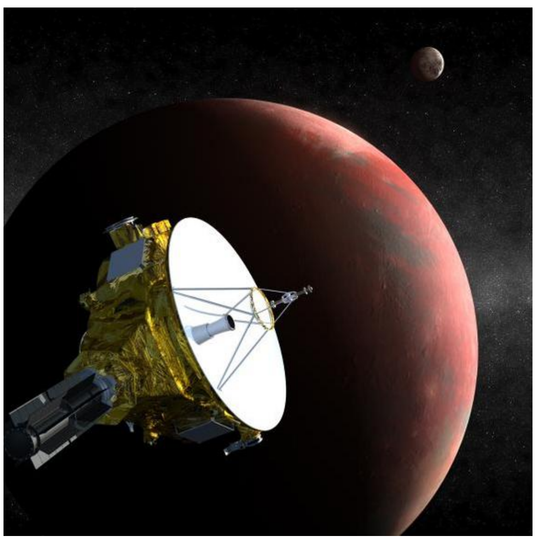
Courtesy of NASA / JPL-Caltech / R. Hurt

Exploring Interplanetary Communication

It is almost impossible for us to understand the vastness of our solar system. Most of us have some mental idea of what a kilometer looks like on a human scale. But when we start talking about millions of kilometers, all of our normal ways of thinking about distances completely fall apart…even for astronomers and rocket scientists!

This problem becomes particularly annoying when we start thinking about communicating across interplanetary distances by light and radio waves. These waves travel at 300,000 kilometers per second (670 million mph). Over a distance of a few meters – say, across a room – travel time is about 3 billionths of a second, a fraction of time that only precision instruments can measure. But when scientists communicate with spacecraft orbiting Mars, travel time for a radio signal can be nearly an hour or more round-trip!

A lot of bad things can happen to a spacecraft over the course of an hour. A rover on Mars can drive into a ditch or over a cliff. NASA spacecraft use some form of artificial intelligence so they can figure most problems out for themselves without waiting for commands from someone on Earth.



Artist rendering of New Horizons near Pluto (NASA)

On July 14, 2015, NASA's New Horizons spacecraft reaches dwarf planet Pluto and begins sending data back to Earth. At that time, the distance from Earth to Pluto is 4.8 billion kilometers. At the speed of light, one-way radio-signal travel time is 16,000 seconds or 4 hours and 27 minutes.

New Horizons makes its closest approach to Pluto at 7:50 am EDT on July 14. Scientists will not get data or images about that event until 4 hours and 27 minutes later or around 12:17 pm EDT, just after lunch!

Space Math Challenge!

For New Horizons, which event do you think we should celebrate? The one at 7:50 am when it arrives at Pluto, or the one at 12:17 pm when we first receive the signal at Earth? **Now try this:** On the same day New Horizons reaches Pluto at a distance of 4.8 billion kilometers, the Voyager 2 spacecraft is 16.1 billion kilometers from Earth. The round-trip radio-signal travel time between Earth and Pluto is 8h 54m. If a radio signal were to be sent to both the New Horizons and Voyager 2 spacecraft on July 14, 2015, at 8:00 am EDT, at what time would the radio signals reach each spacecraft?

Answer: Either time is important to know, but for different reasons!
Now try this: The one-way trip to Pluto takes 4h 27m. Voyager 2 is at a distance 16.1/4.8 = 3.35 times farther than Pluto, so it will take (4h 27m)x 3.35 = (267m)x 3.35 = 894 min or 14 hours and 54 minutes to get from Earth to Voyager 2. The signal would reach Pluto at 8:00 am + 4h 27m = 12:27 pm. It would reach Voyager 2 at 8:00 am + 14h 54m = 22:54 or 10:54 pm on July 14.

Exploring the Dwarf Planet Pluto

High-resolution image of Pluto viewed by New Horizons spacecraft on July 14, 2015.
(Image credit: NASA/JHUAPL/SwRI)

Exploring Dwarf Planet Pluto

With a diameter only about 1/3 that of our Earth, Pluto is still a very complicated object. We know it has enough mass that its gravity has pulled its surface into a spherical shape. Its density is between that of solid ice and rocky granite, so its interior must contain both of these ingredients. Gravity is strong enough to segregate these materials. The denser rocky material is believed to reside in a core region surrounded by less-dense mantle material. The rocky core occupies about 70% of Pluto's radius. The core is massive enough that radioactive materials can heat the core and allow some of the icy mantle material to become liquid. Today, a subsurface ocean layer of liquid water may still exist some 180 kilometers deep at the warm boundary between the core and the mantle.

Scientists believe that Pluto's massive moon Charon formed in a similar way to our own moon. A large object collided with Pluto and ejected material into an orbiting ring. Some of this material then came together to form Charon. For Earth, this event happened about 100 million years after Earth formed, and was followed by a period called the Late Heavy Bombardment Era. Millions of asteroids collided with Earth and the moon forming the craters on the moon. These craters were eliminated on Earth by volcanic activity and erosion. For Pluto, the event may have happened much later because neither Charon nor Pluto show signs of intense cratering. One intriguing possibility is that Pluto may have a large sub-surface ocean heated by radioactive decay in the rocky material. Craters would have been erased by the intense volcanic activity on Pluto's surface after Charon's formation. Unlike Earth volcanoes, the Pluto volcanoes may have ejected liquid water like the cryovolcanoes (ice volcanoes) on Neptune's moon Triton. Over time, this material resurfaced Pluto covering any remaining impact craters, and leaving behind the surface we see today.

Pluto also has a thin atmosphere of nitrogen, methane and carbon monoxide. It freezes and condenses to the ground during Pluto's orbital winter. Pluto's reddish color is believed to be due to deposits of organic compounds on its surface called tholins.

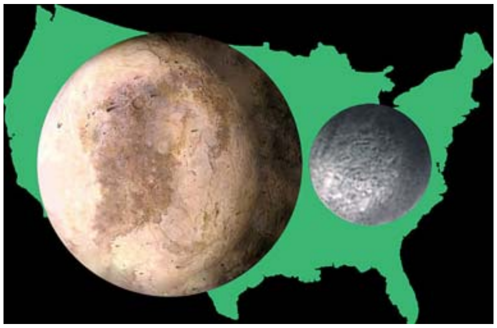
Space Math Challenge!

Pluto has a diameter of 2,368 km. If the crust of Pluto extends from the subsurface ocean layer to the visible surface, about how thick is the crust of Pluto? **A bit more difficult**: Suppose the 'Heart of Pluto' is a deposit of ice 10 km thick that covers all the craters below it. If its area from the photo is 600,000 km^2, how many Greenland Ice Sheets-worth of ice does this represent if the Greenland Ice has a volume of 2.8 million km^3?

Answer: The core extends to 70% of the radius (1184 km) or 829 km, and the ocean is 180 km thick on top of the core, so the crust could be 1184-829-180=175 km thick. **A bit more difficult:** Volume=Area x height = 10 km x 600,000 km^2 = 6 million km^3. This is about twice the volume of the Greenland Ice sheet.

Comparing Pluto and Earth

Comparing Pluto and Earth


Pluto and Charon compared to the continental United States.


Earth as seen from space.


Pluto as viewed by the New Horizons spacecraft on July 14, 2015.

The diameter of Earth is 12,742 kilometers, while the diameter of Pluto is only 2,368 kilometers, making this dwarf planet a relatively very small object indeed.

Earth is composed of an iron/nickel core and a mantle rich in rocky materials such as basalts and granites. Pluto has a rocky core with probably little iron, and a thick mantle of ice. Pluto may also have a liquid-water ocean sandwiched between its core and its outer crust. On Earth, a liquid-water ocean only exists in a thin band atop its outer crust.

Both Earth and Pluto have atmospheres that are rich in nitrogen, however instead of oxygen as the next most abundant compound as for Earth's atmosphere, Pluto has methane. Methane is a common compound among many objects of the outer solar system.

The atmosphere of Pluto is about one million times thinner than that of Earth. This low density means that ultraviolet light can easily reach the surface of Pluto and cause different kinds of chemical reactions. In the atmosphere, these reactions produce reddish compounds called tholins that are not found in Earth's atmosphere. Tholins may also account for the red color of Jupiter's Great Red Spot.

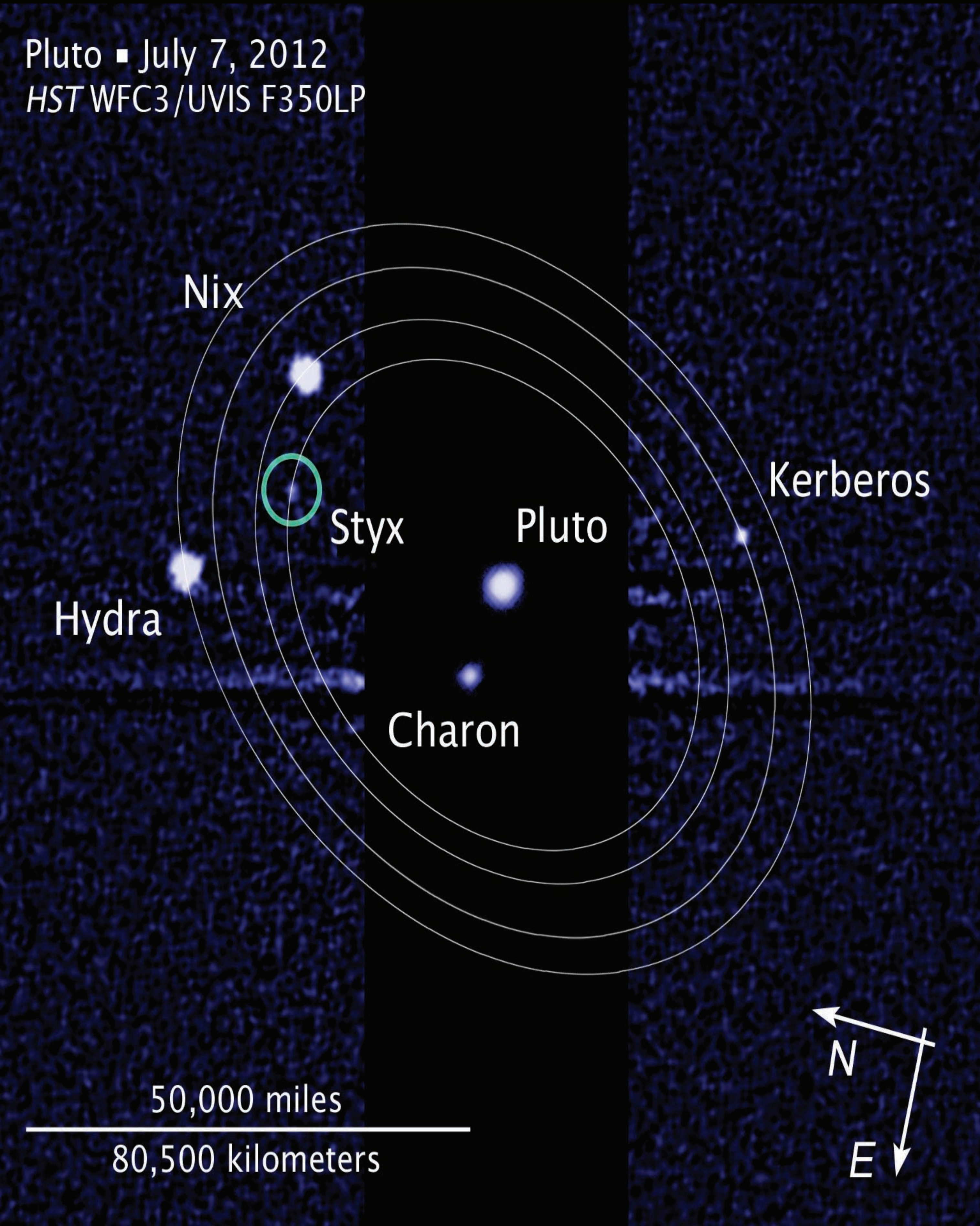
The moons of both Pluto and our Earth may have been formed the same way. A large body may have collided with Pluto and Earth, ejecting material into orbit. This material then collected together by gravity and formed these two giant moons. Both Earth and Pluto have been called 'Double Planets' due to the large sizes of their major satellites compared to Earth and Pluto.

Space Math Challenge!

How many Plutos can fit side-by-side across the diameter of Earth? **A bit harder**: The land surface of Earth is 1/7 Earth's total surface area. About how big is Pluto's surface area compared to Earth's land area?

Answer: 12742 km /2368 km = 5.4 or about 5. **A bit harder**: Pluto surface area is $(2368/12742)^2$ = 1/29 Earths. This is 7/29 = ¼ Earth's land area!

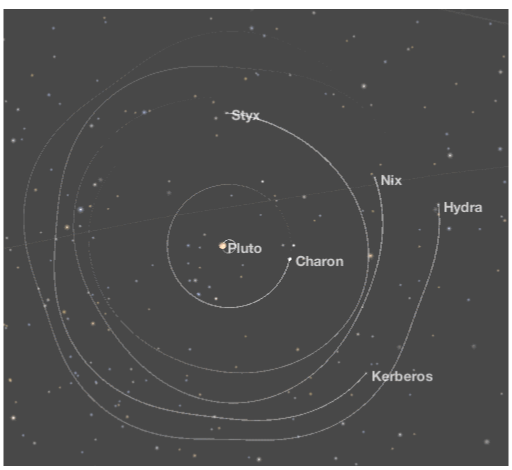
The Moons of Pluto



The Moons of Pluto

Pluto's moon Charon (NASA/New Horizons)

Moon	Diameter (km)	Period (days)
Charon	1,207	6.4
Styx	10 x 25	20
Nix	56 x 26	25
Kerberos	13 x 34	32
Hydra	58 x 34	38



Orbits of Pluto's moons (*Eyes on the Solar*

The moons of Pluto are a remarkable collection of five objects that could not possibly have gathered together through random captures over time. The reason we know this is that each of the four outer moons are nearly the same size, and orbit Pluto in essentially the same orbital plane. Also, a moon cannot be captured by Pluto's gravity by merely coming close to it. Significant amounts of energy and momentum would have to be lost for the moon to settle into a stable orbit.

The fact that the moons all orbit in the same plane around Pluto means that, instead of being captured, they were probably originally formed that way, just like the moons of Jupiter and those of the outer planets.

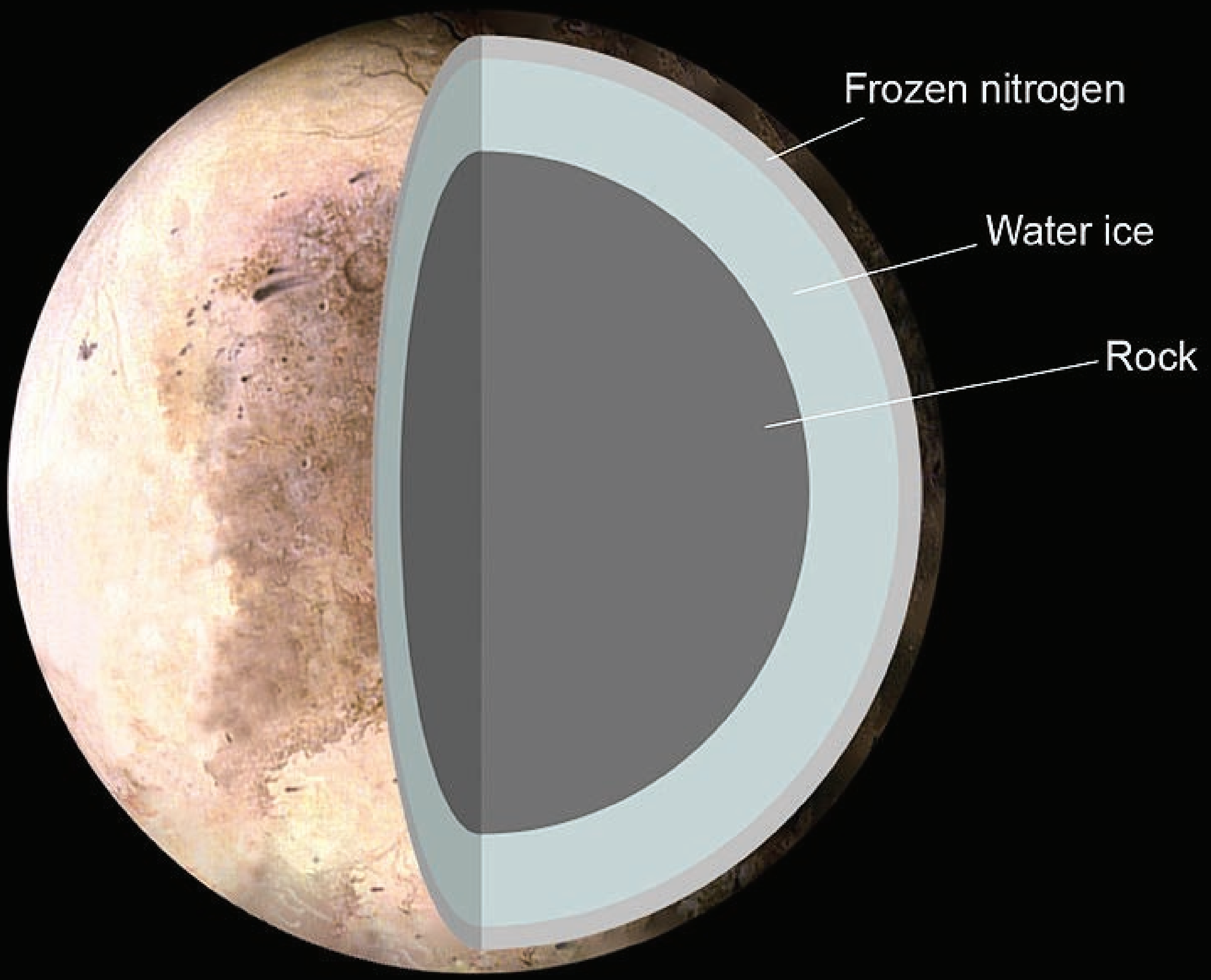
Scientists think that, like Earth's moon, Charon was formed after a massive object struck Pluto and ejected debris into orbit around Pluto. The debris formed a rotating disk of gas, dust and asteroidal fragments from the size of beach sand and basketballs, to objects many kilometers across. Over millions of years, these fragments came together to form the large moon, Charon, and other smaller objects. The four outer moons of Pluto are the last survivors of this moon-making population. All the other material was eventually ejected into space. The New Horizons spacecraft passed through Pluto's orbit plane without a single collision by any dust or remaining debris. The four small moons are the largest they can possibly be without upsetting the delicate balance of pushes and pulls they produce upon each other. Over the coming eons, only Charon will remain as this dance of gravity ejects the smaller moons one by one.

Space Math Challenge!

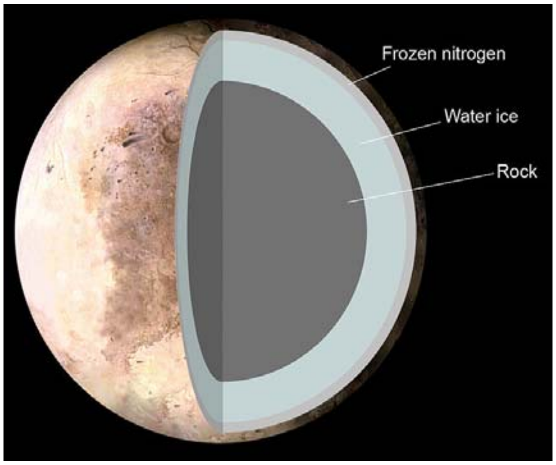
If Styx and Nix started out in their orbits opposite (closest) to each other on July 14, 2015, how long would it take for them to once again repeat this pattern? **A bit harder:** How long will it take Styx and Hydra to repeat their closest approach?

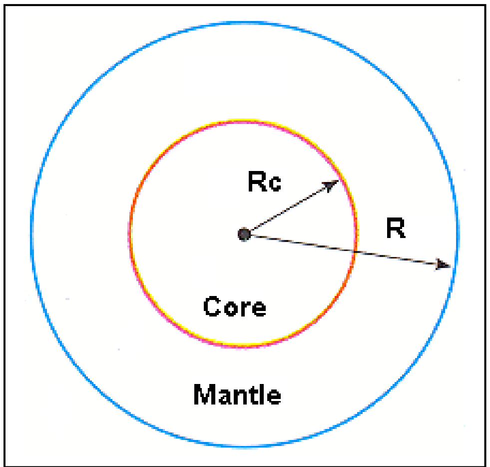
Answer: Styx has a period of 20 days and Nix has a period of 25 days so their time series are: Styx=0,20,40,60,80,100 and Nix=0,25,50,75,100, so after 100 days they will again be opposite each other. **A bit harder**: Method 1) The time series for Styx is 0,20,40,60,….380 And for Hydra it is 0, 38, 76, 114,…380, so the common moment occurs after 380 days. Method 2) Using the Greatest Common Multiple: Styx 20=2x2x5 and Hydra 38 = 2x19, so GCM=2x2x5x19= 380 days.

Inside Pluto



Inside Pluto





Densities of Common Materials

Material	Density (kg/m^3)
Liquid Hydrogen	70
Methane Ice	900
Water Ice	917
Salt Water	1030
Sandstone	2200
Marble	2400
Granite	2700
Iron Ore	4500
Lead Ore	7500

For Pluto, we know from observations that its diameter is about 2368 kilometers, and its mass is about 1.3×10^{22} kilograms. Pluto is a sphere, so its volume is just $V = 4/3\pi R^3$ or about 7.0×10^{18} cubic meters. The average density of Pluto is then about 1900 kg/m^3. From our table of common materials, this means its average density is somewhere between that of water ice and sandstone!

So already we have learned a lot about Pluto. It is not a body made entirely of ice or rock, but it is a mixture. Usually when a round object forms, gravity lets the denser material settle to the core, so we suspect that Pluto has an outer layer of ice and an inner core made of a rocky material. Let's use Mass = Density x Volume to make a better model!

A two-density model for the interior

The core has a radius of Rc and a density of Dc. The outer shell has an inner radius of Rc and an outer radius of R= 2368/2 = 1184 km. It has a density of Dm. The total mass of Pluto is 1.3×10^{22} kg. We have to select Rc and the two densities Dc and Dm so that when we add their masses we get exactly the observed mass of Pluto.

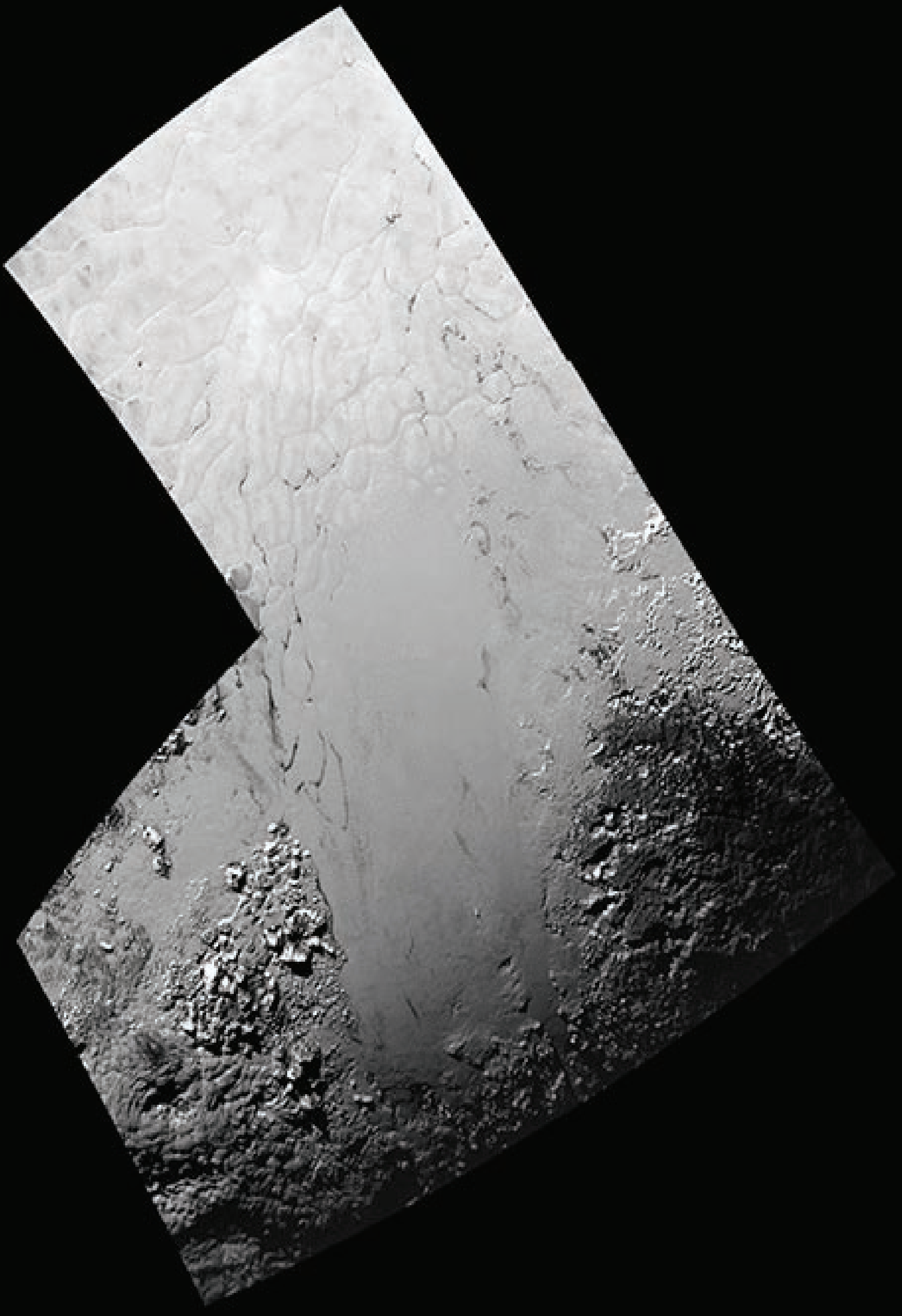
$$\text{Core Mass} = D_c\left(\frac{4}{3}\pi R_c^{\,3}\right)$$

$$\text{Shell Mass} = D_m\left(\frac{4}{3}\pi R^3 - \frac{4}{3}\pi R_c^{\,3}\right)$$

Space Math Challenge! From the formula for the volume of a sphere, verify that the average density of Pluto is 1900 kg/m^3. **A bit harder**: If the core radius Rc= 830 km, and Dc=2700 kg/m^3 and Dm=917 kg/m^3, and R=1184 km, what is the predicted mass for Pluto?

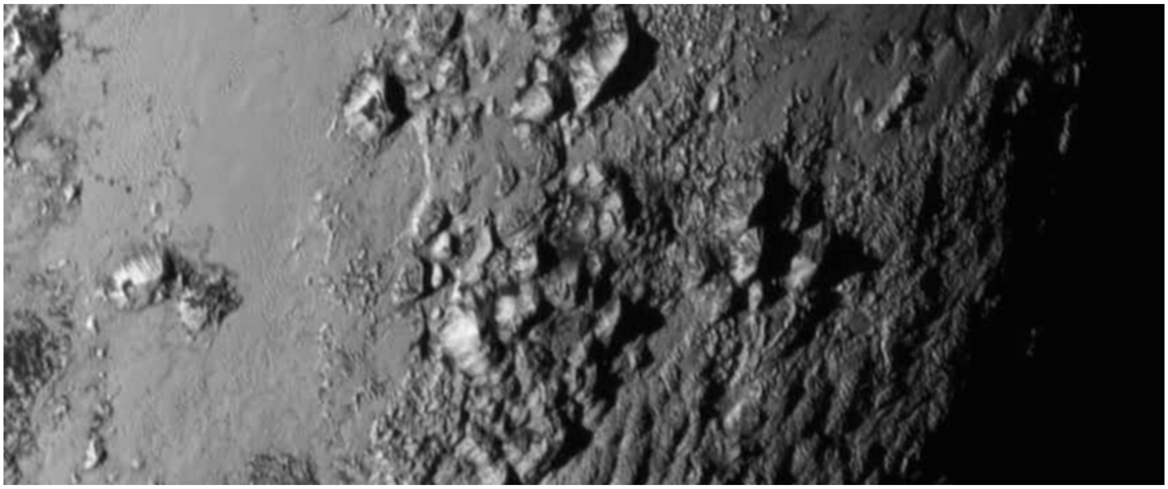
Answer: $V = 4/3\pi\ (1184000\ \text{meters})^3 = 6.95 \times 10^{18}\ m^3$. Density = 1.3×10^{22} kg/$6.95 \times 10^{18}\ m^3$ = 1,900 kg/m^3 after rounding to two significant figures. A bit harder: Core mass = 6.44×10^{21} kg. Shell mass = $917(6.95 \times 10^{18}\ m^3 - 2.39 \times 10^{18}\ m^3) = 4.18 \times 10^{21}$ kg so M = 1.06×10^{22} kg. This model accounts for 82% of Pluto's actual mass. Can you do better than this?

Exploring Pluto's Surface



Absence of cratering in Norgay Montes and Sputnik Planum as seen from 70,000 km by the New Horizons spacecraft, July 14, 2015. (Image credit: NASA/JHUAPL/SwRI)

Exploring Pluto's Surface



This image was taken by NASA's New Horizons spacecraft on July 14, 2015 as it flew by Pluto. The width of the scene is about 150 miles (240 km) and covers an area of about 20,000 km^2. That is about as big as the state of Massachusetts! The most important question posed by what the scientists see in this remarkable image is "Where are all the craters?"

Craters are a common feature of objects in our solar system such as our moon or satellites of the giant planets whose surfaces have remained unchanged since the solar system's formation. Other large satellites such as Io, Europa and Triton have few craters because their surfaces have changed due to volcanism, or to the enormous gravitational deformations by the giant planets they closely orbit. For Pluto, its scoured surface appears to be very young and free of craters, but it is not in orbit around a larger planet capable of providing this energy. One possibility is that there is just enough heat energy inside Pluto left over from its formation, to have created geysers. Perhaps when its icy crust was much thinner than it is today, these ancient geysers spewed out debris, which rained down across Pluto and slowly covered whatever craters may have existed.

Another feature of Pluto is its mountains. The outer crust of Pluto is made from water ice and not rock, so the mountains we see are made from solid ice. At the extreme cold temperatures of Pluto (-218 Celsius) water ice is actually as strong as solid rock. On Earth, pure ice mountains in the Arctic region are rarely 100 meters tall. But on Pluto these ice mountains appear to be over 3,700 meters tall! How were such enormous ice mountains formed without melting them from the energy needed to create them?

Many of the questions we have today about Pluto will be answered in the coming years, but for now we can only marvel at our new knowledge and the new questions to come.

Space Math Challenge!

Jupiter's icy moon Callisto has about 0.01 craters per square kilometer. How many craters would you predict for the above image of Pluto? **A bit more difficult**: The radius of Pluto is 1,184 km. How many craters would you have expected to see in the hemisphere facing the New Horizons spacecraft?

Answer: Craters = 20000 km^2 x 0.01 craters/km^2 = 200. A bit more difficult: Hemisphere area = 2 π $(1184)^2$ = 8.8 million km^2. Craters = 0.01 craters/km^2 x 8.8 million km^2 = 88,000 craters.

Additional NASA Resources

Videos:

Eight NASA videos describing the New Horizons mission.
http://www.nasa.gov/mission_pages/newhorizons/videos/index.html

Youtube Video: Arrival at Pluto:
https://www.youtube.com/watch?v=_LBJz4TxG0I

CNN Video: New Horizons spacecraft nears Pluto:
http://www.cnn.com/videos/us/2015/01/26/orig-new-horizons-probe-nears-pluto-nasa.cnn

ABC News: New Horizons Videos
http://abcnews.go.com/topics/news/science/new-horizons-mission.htm?mediatype=Video

Mission Pages:

Applied Physics Laboratory mission page
http://pluto.jhuapl.edu/

New Horizons NASA mission page
http://www.nasa.gov/mission_pages/newhorizons/main/index.html
NASA Plutotime calculator and image gallery
http://www.nasa.gov/feature/nasa-lets-you-experience-pluto-time-with-new-custom-tool

Solar System Exploration: Pluto
https://solarsystem.nasa.gov/planets/profile.cfm?Object=Pluto

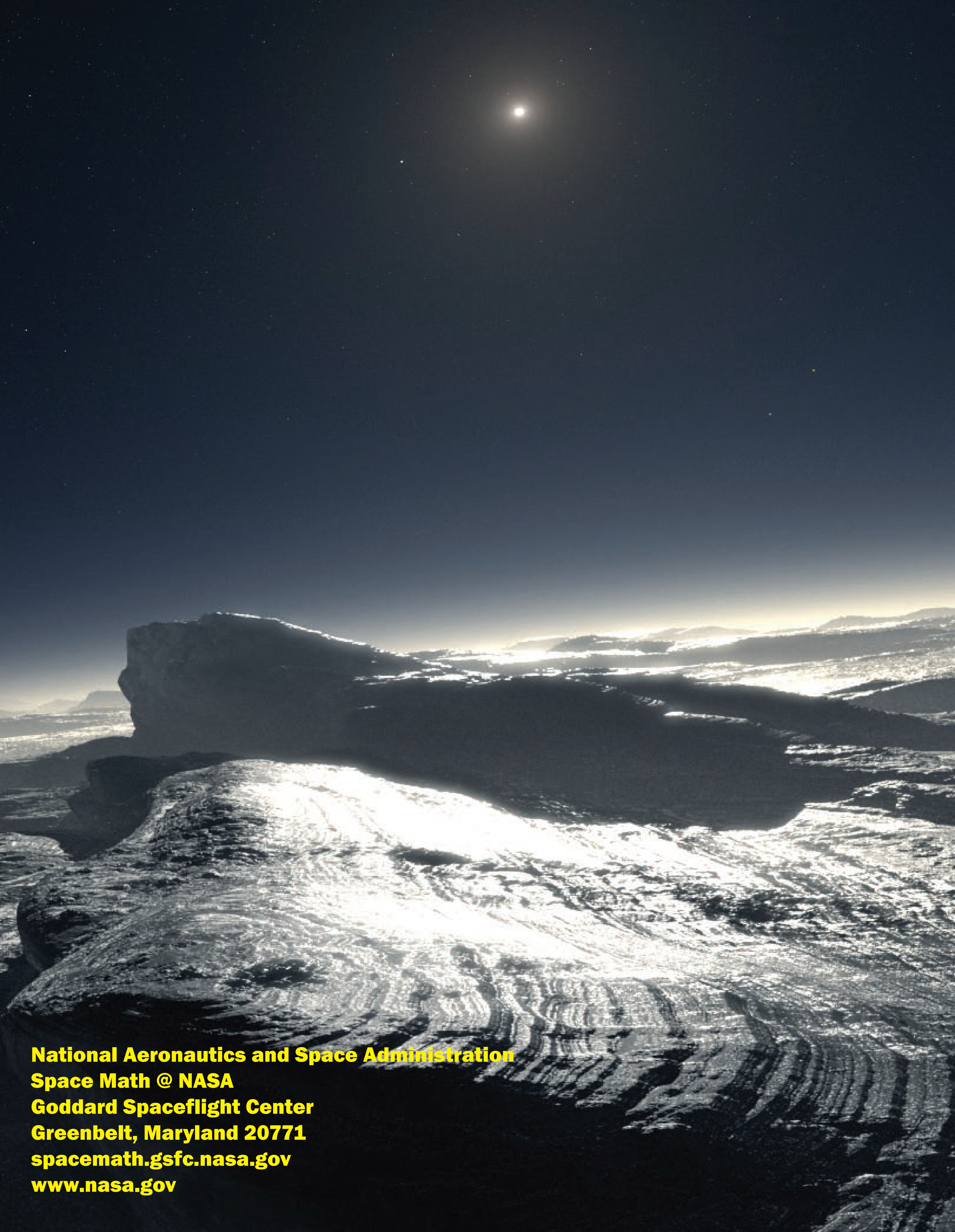
Eyes on the Solar System
http://tinyurl.com/pgxzumf

Press Releases:

New Horizons news release archive
http://www.nasa.gov/mission_pages/newhorizons/news/index.html

NASA press releases archive
http://nasasearch.nasa.gov/search?utf8=%E2%9C%93&affiliate=nasa&query=pluto

Applied Physics Laboratory
http://pluto.jhuapl.edu/index.php



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